

2005 DEER Conference

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LD Diesels in U.S. Marketplace

***Technical Progress Will Lead to
Cost-Effective Business Cases***



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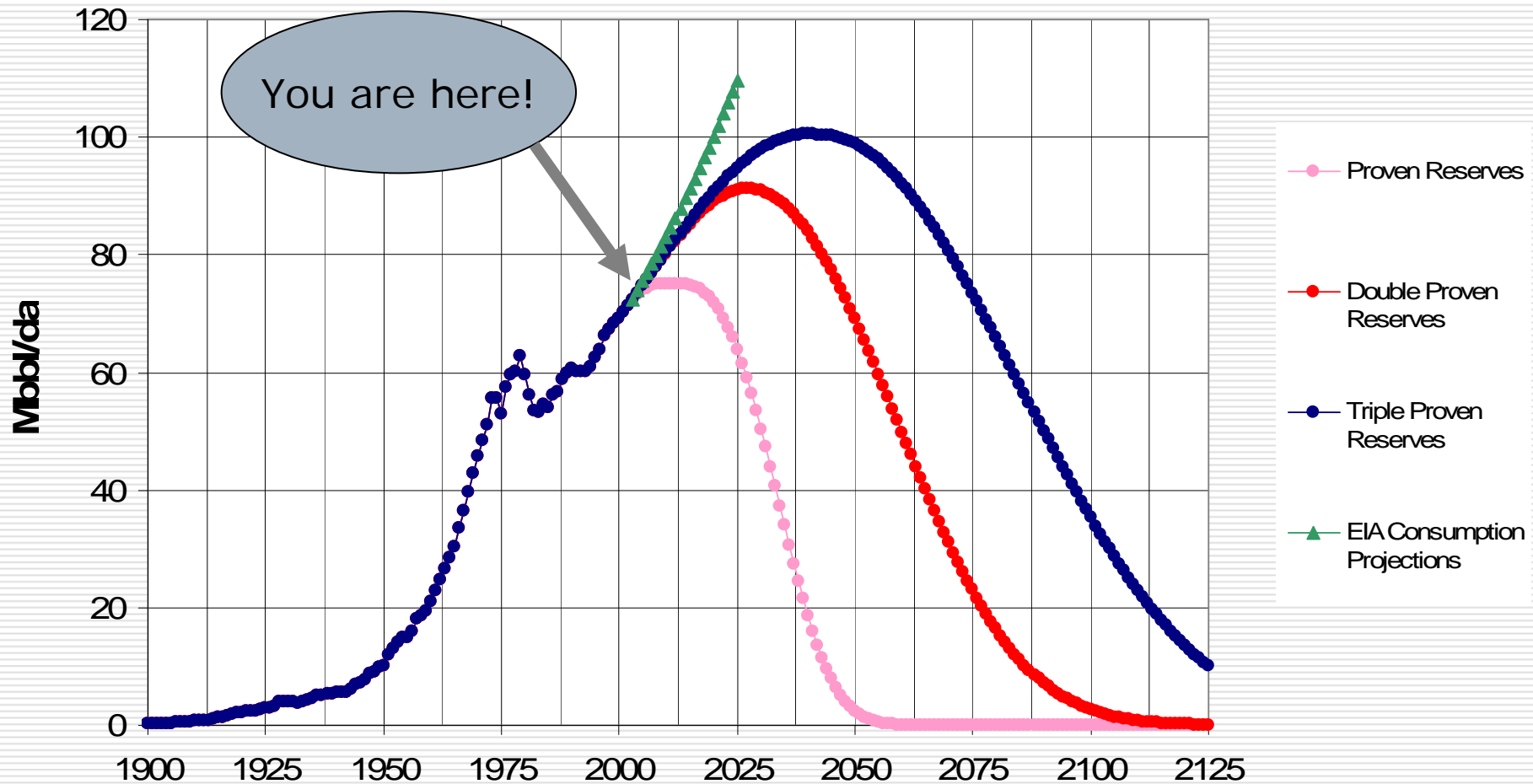
Clean Automotive Technologies

www.epa.gov/otaq/technologies

The Drivers for Increasing LD Diesels in US Marketplace

1. Expected higher costs of petroleum
2. Expected higher costs of petroleum
3. Expected higher costs of petroleum
4. Expected higher costs of petroleum

Projections for World Crude Oil Production



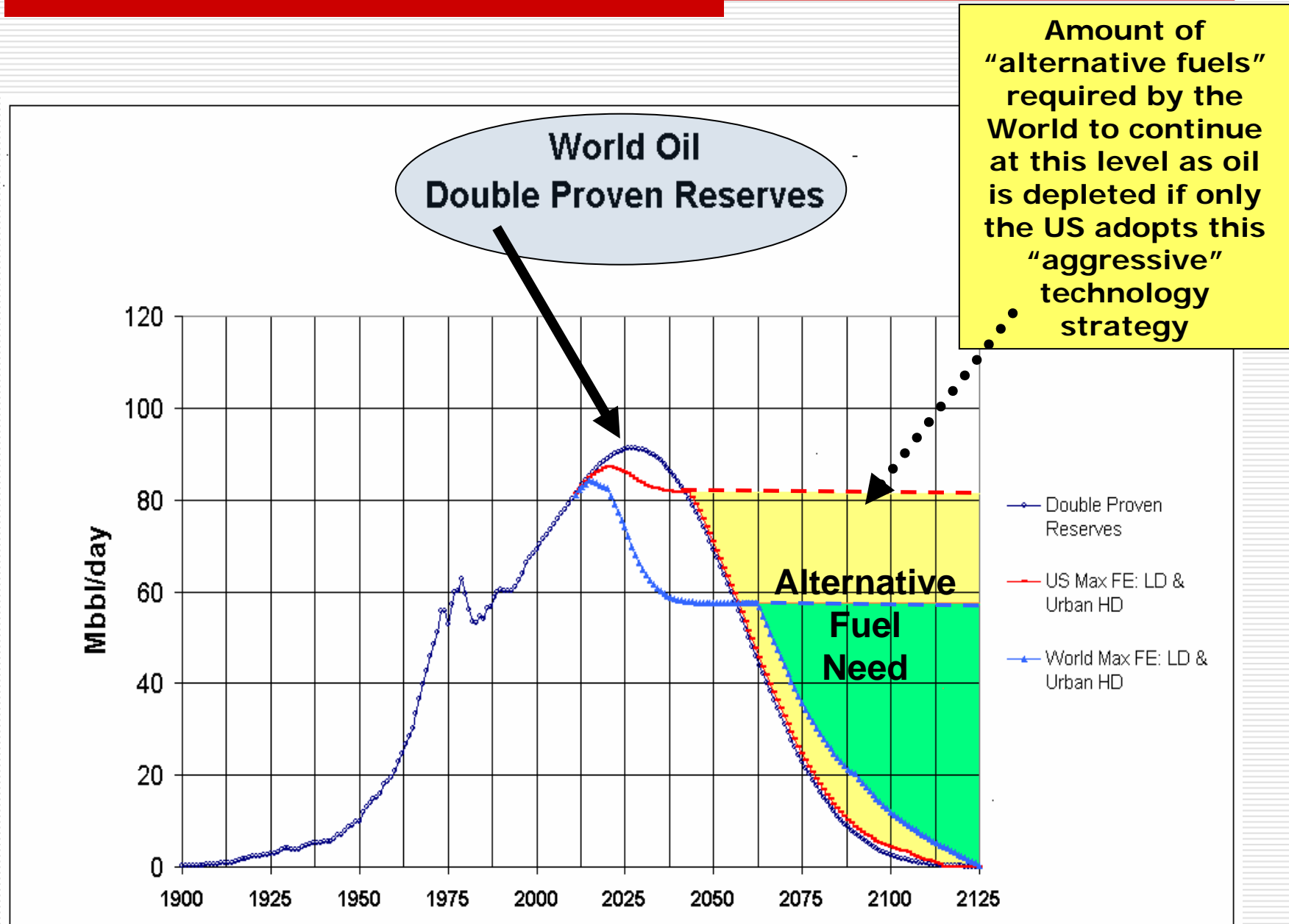
Transportation in the Pre-Oil Era



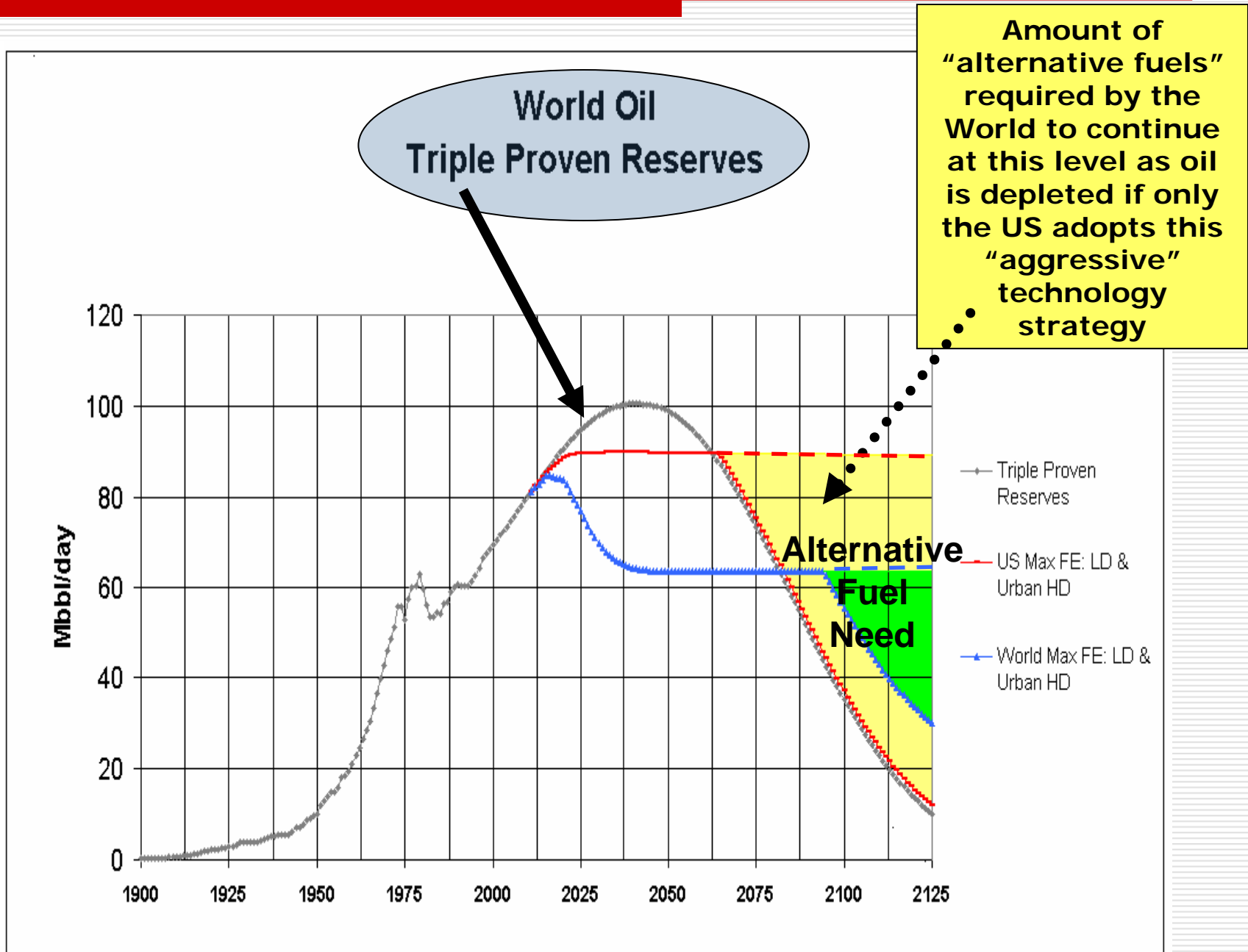
Transportation in the Post-Oil Era



Impact of "Aggressive" Conservation



Impact of "Aggressive" Conservation



Logical Conclusions...

1. **We need fuel conservation - ASAP**
2. **Diesels are the technology which could be implemented quickly and broadly** (diesel hybrids, waste heat recovery, further improvements to aero and rolling resistance, weight reductions... will follow)
3. **Plans for fuel transition should begin - ASAP**

State of Clean Diesel Solutions - Making Technical Progress...

Diesel Options to Meet LD Tier 2 or HD2010 On-Road Emissions Levels

NOx Adsorber Aftertreatment

- Viable approach (primary path for compliance)

SCR Aftertreatment

- Infrastructure, cost, significant compliance and enforcement concerns – engine manufacturers responsible for in-use compliance

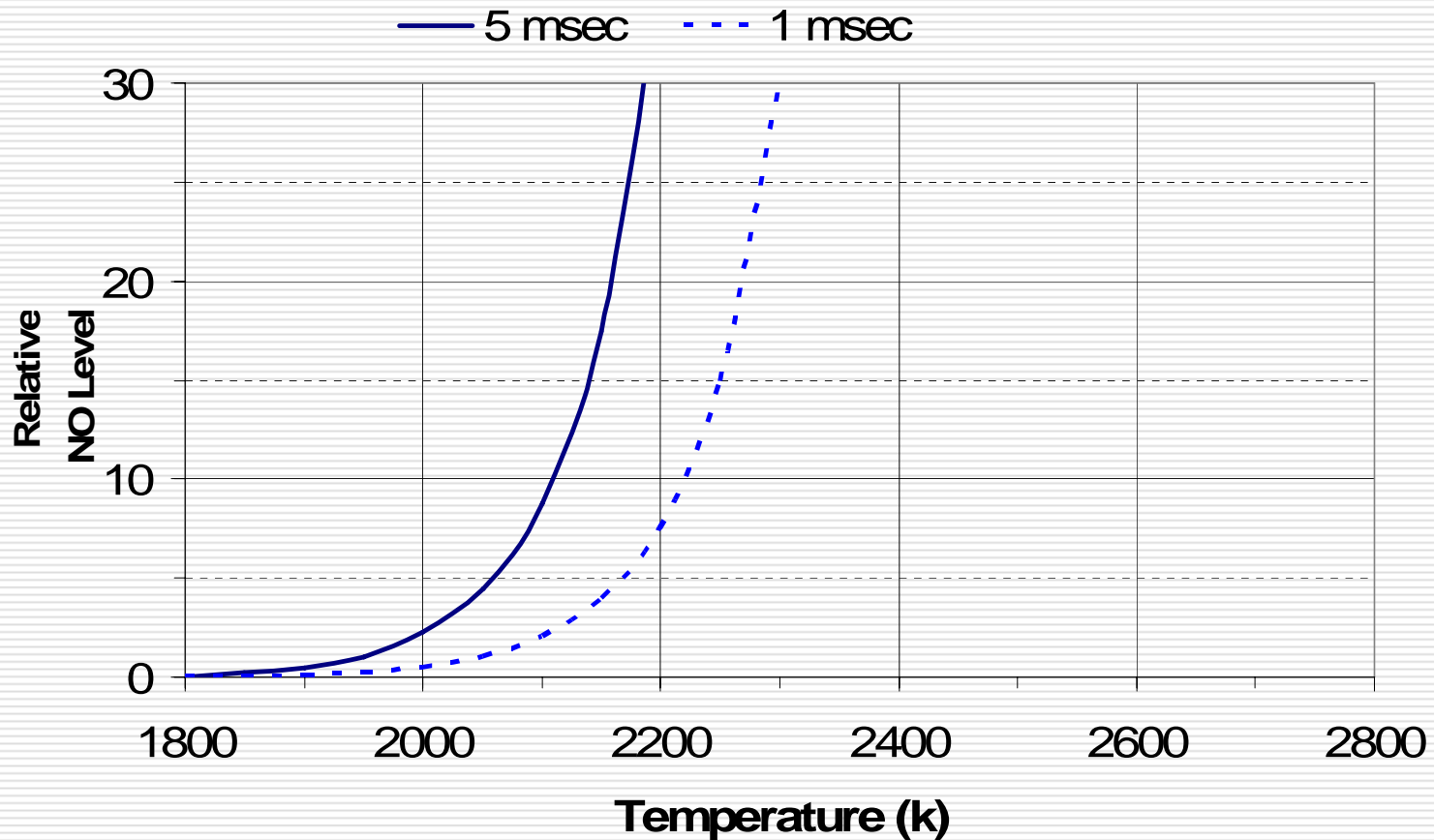
Clean Diesel Combustion

- Control NOx Engine-out & Smoke/PM/HC with Conventional Aftertreatment

Clean Diesel Combustion

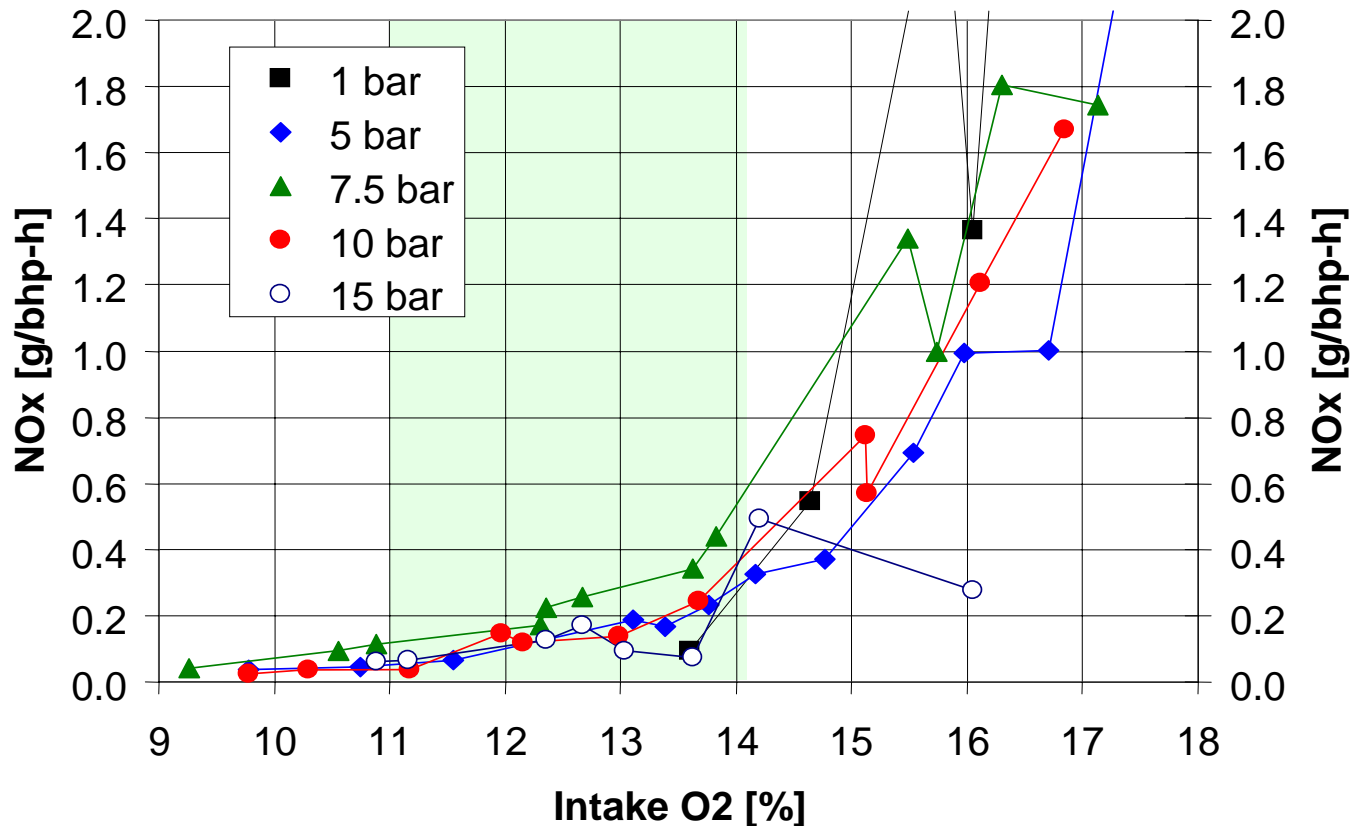
- ☐ What Is It?
- ☐ Initial Results
- ☐ Challenges / Opportunities

Basic NO_x Production versus Combustion Temperature



EPA's Approach to Clean Diesel Combustion NOx Control

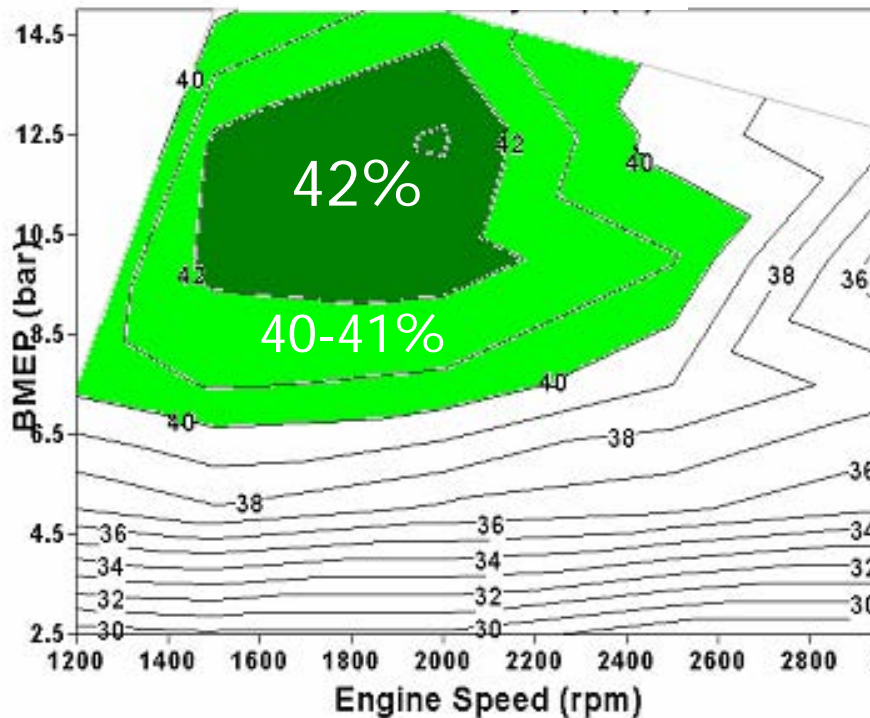
If you keep intake oxygen concentration between 11% and 14%, then combustion temperature will be below 2000 Deg K.



Good Efficiency with Low Engine-Out NOx

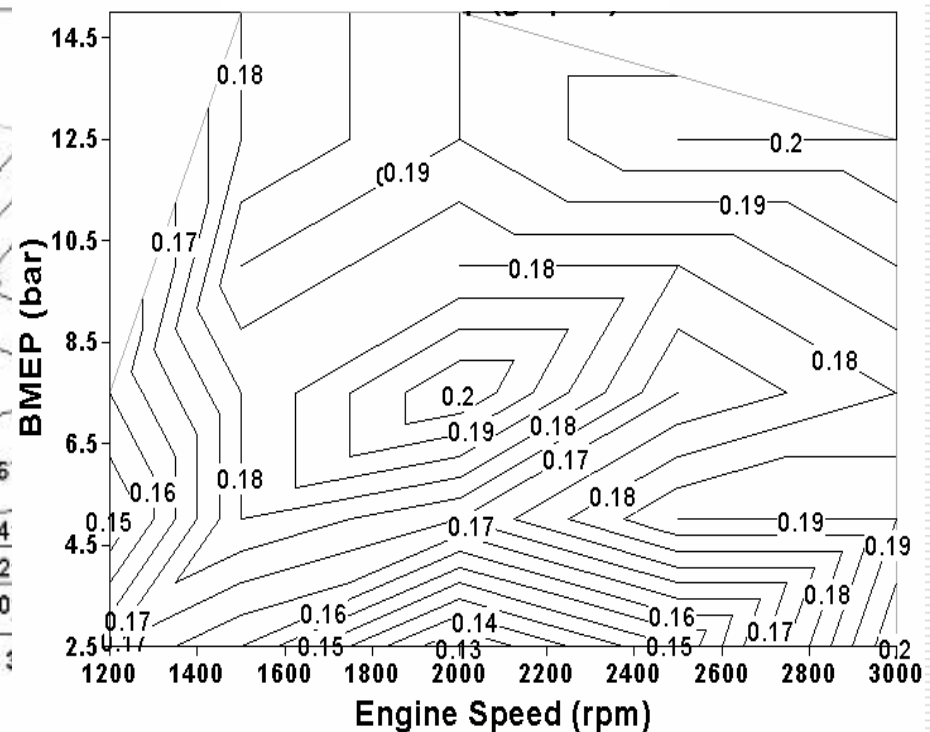
1.9L 4-cyl

Engine Brake Efficiency (%)



$$P_{\text{exhaust}} = P_{\text{input}} + .1 \text{ Bar}$$

Brake Specific NOx (g/hp-hr)



NOx below .2 everywhere

Update on Clean Diesel Combustion

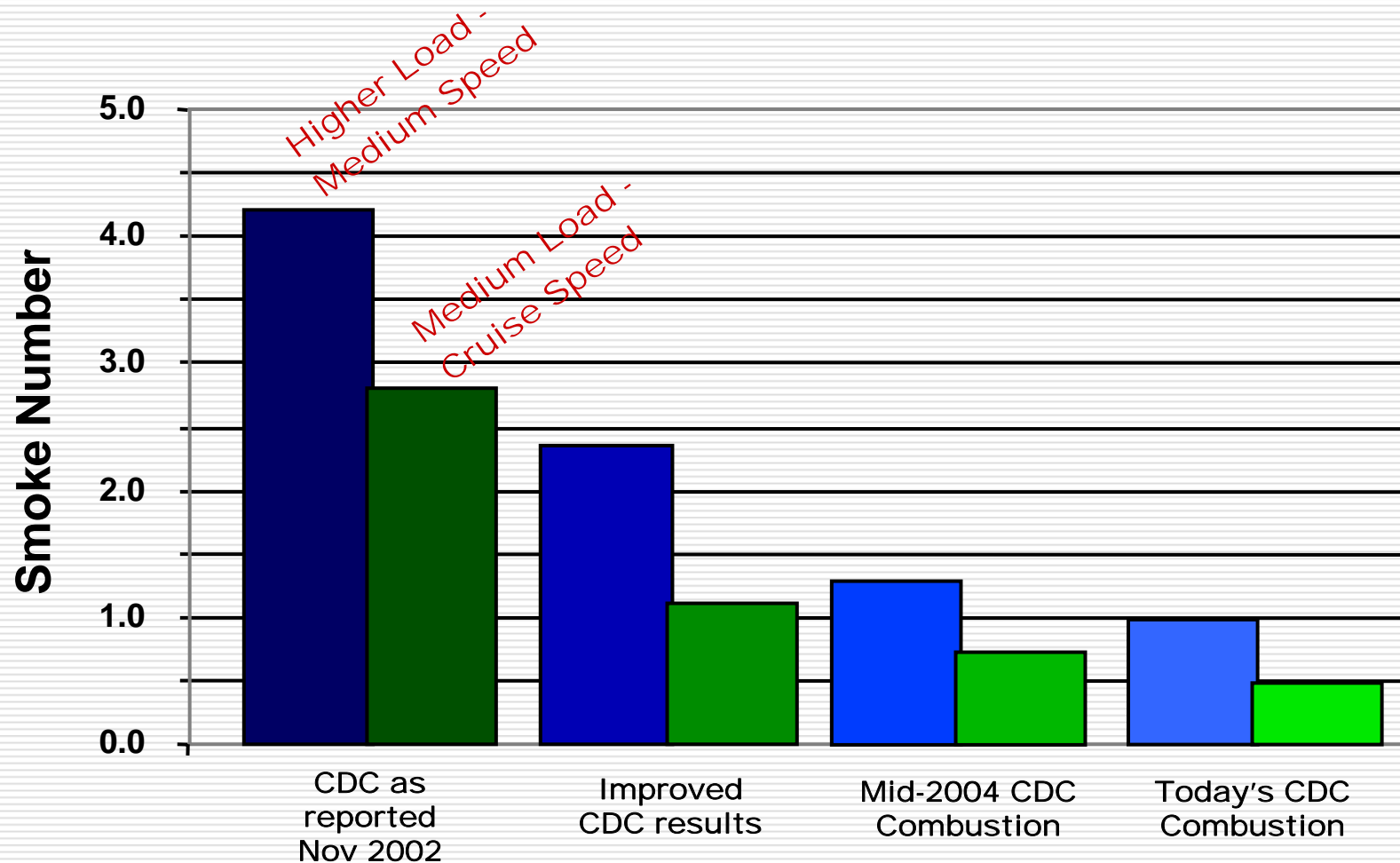
Initial Vehicle Test Results

Engine	Test	Fuel Economy (mpg)	HC(g/mi)	CO	NOx	PM
Stock	FTP city	32	0.05	0.10	0.8	0.028
	FTP hwy	49	0.01	0.02	0.7	0.027
	US06	32	0.01	0.03	1.8	0.069
Tier 2	Bin 5 (120k mi)		0.09	4.20	0.07	0.010
CDC	FTP city	30	0.23	1.12	0.06	0.001
	FTP hwy	47	0.10	0.18	0.05	0.0004
	US06	26	0.20	0.07	0.14	0.008

VEHICLE: ~ 4,200 lb test weight
 a larger-wagon or mini-van

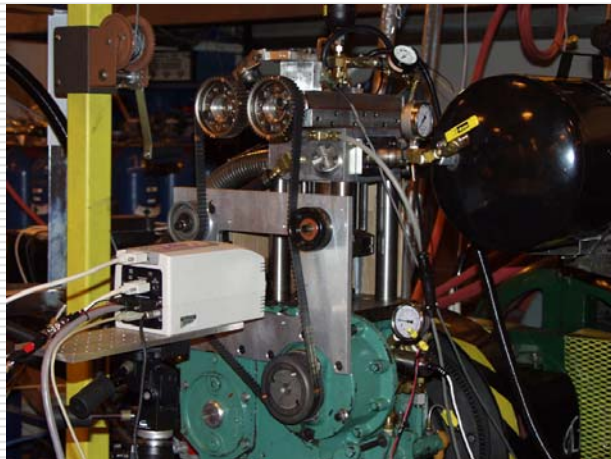
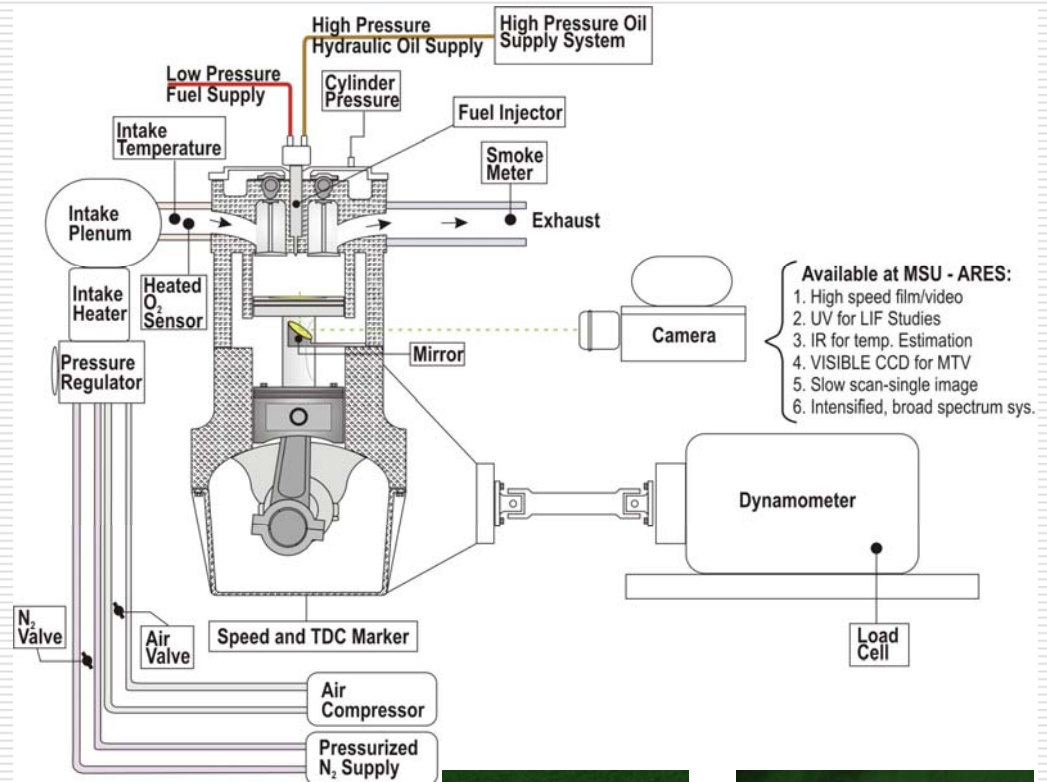


Continuing to Improve Performance & Reduce PM



Infrared Combustion Analysis Equipment/Setup

Camera Information	
Camera	Merlin MID
Manufacturer	FLIR
Detector Type	InSb
Detector Cooling	Integral Sterling
Spectral Range	1.5-5 μm
Temperature Range	0-2000 $^{\circ}\text{C}$
Thermal Sensitivity	0.025 $^{\circ}\text{C}$ *
Accuracy	± 2 $^{\circ}\text{C}$, ± 2 % *
Array Format	320 x 256 FPA
Image Frequency	60 Hz
Integration Time	10, 20 μs
* Dependent on emissivity	



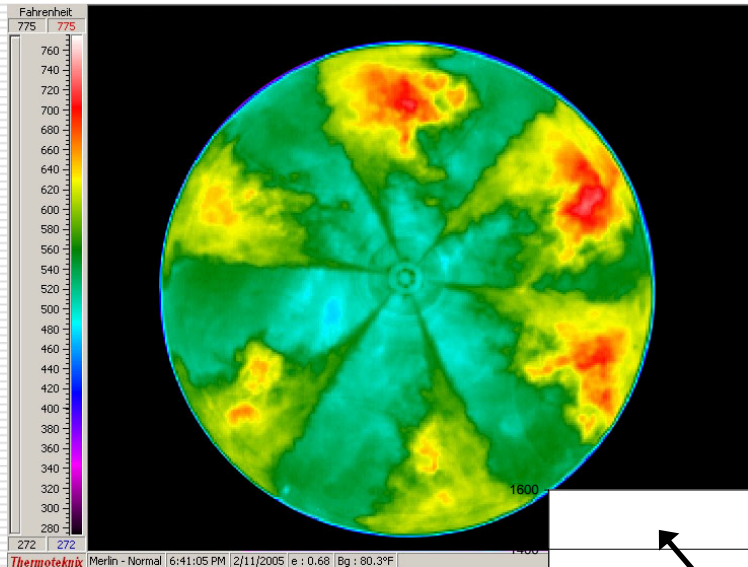
Michigan State University College of
Engineering



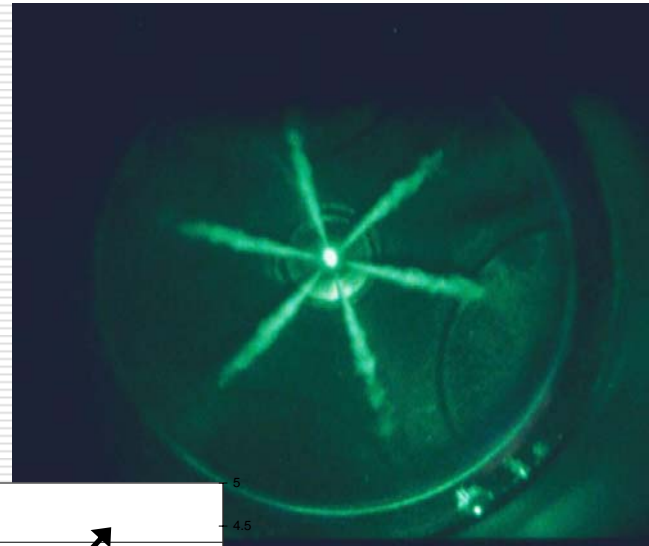
Sapphire Insert & Assembled bowditch piston

Study of Fuel Injection As it Occurs Just Before Combustion Event

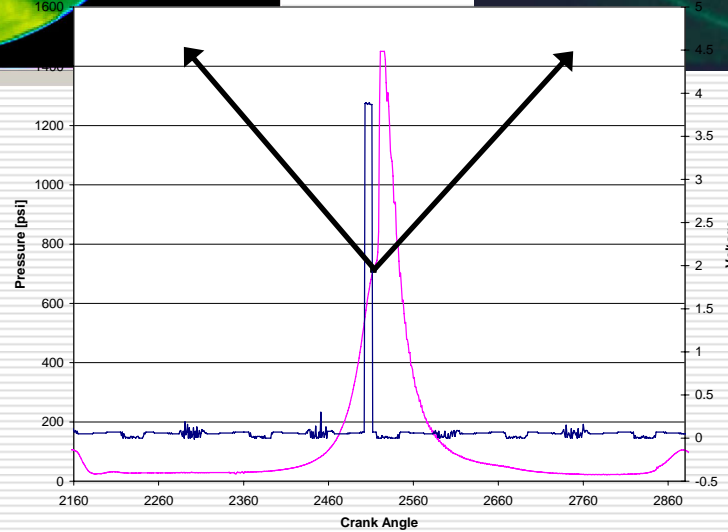
IR Images
10deg After SOI



High Speed Imaging-10kfps
10deg After SOI



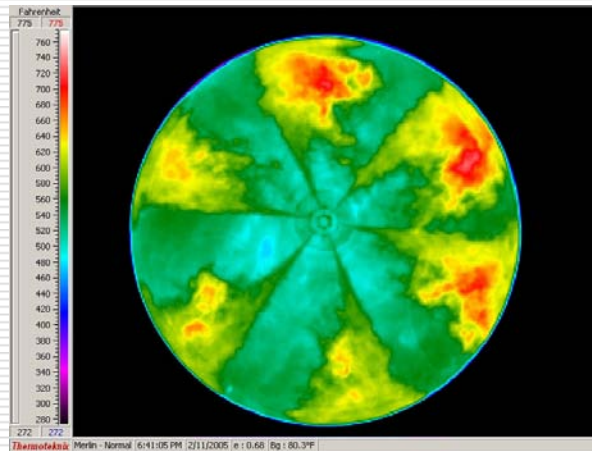
gas phase vs. liquid phase
for normal diesel injection



Normal Diesel Combustion and Clean Diesel Combustion

Normal Diesel Combustion

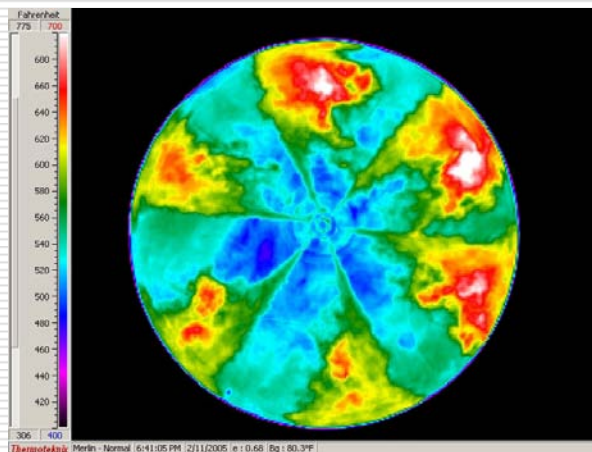
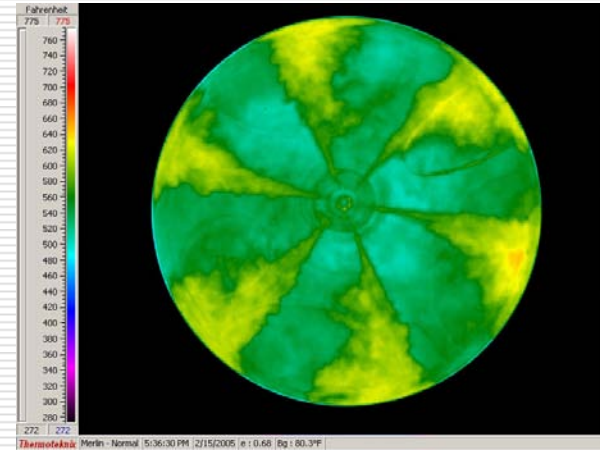
10deg After SOI



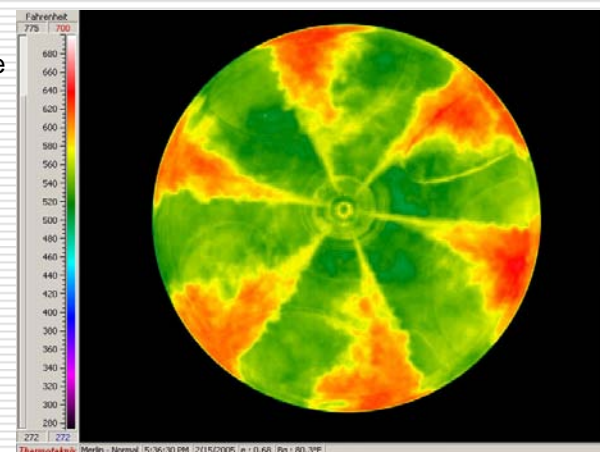
Set Temperature
Scale: 272-775 F

Clean Diesel Combustion

10deg After SOI



Optimized
Temperature Scale



IR Images



IR Images

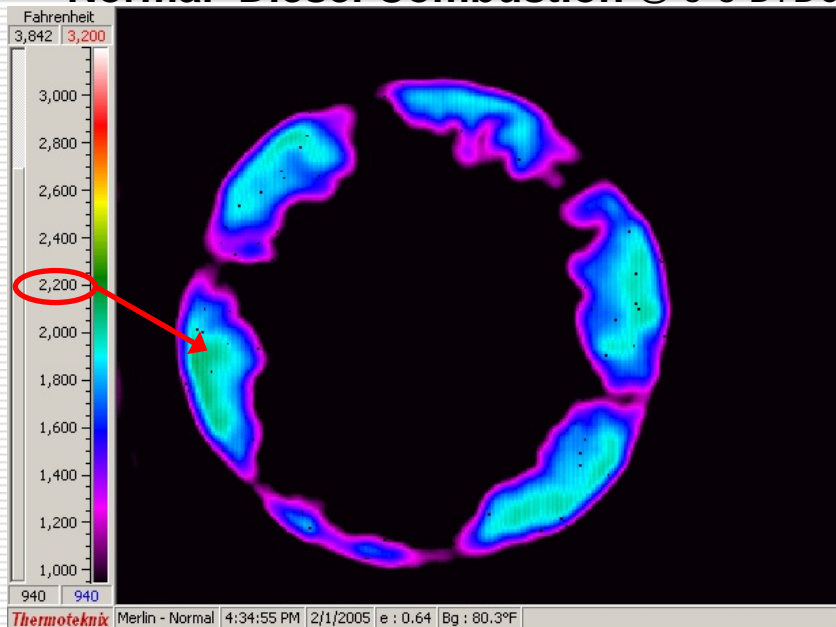
Clean Diesel Combustion *is COOLER Combustion (~550 °C)*

Engine Firing Conditions

Combustion Mode	Engine Load BMEP [Bar]	Boost [Bar Abs]	Intake O2 [%]	Speed [RPM]	Commanded Start of Inj BOI [°BTDC]	Fueling Rate [kg/hr]	Injection Duration [ms]	Hydraulic Injection Pressure [psi]	Peak Cylinder Press [Bar]
Clean Diesel	10	1.8	13.5	2000*	17.5	1.7	1.02	3000	135
Normal Diesel	10	1.5	20.9	2000*	17.5	1.7	1.02	3000	

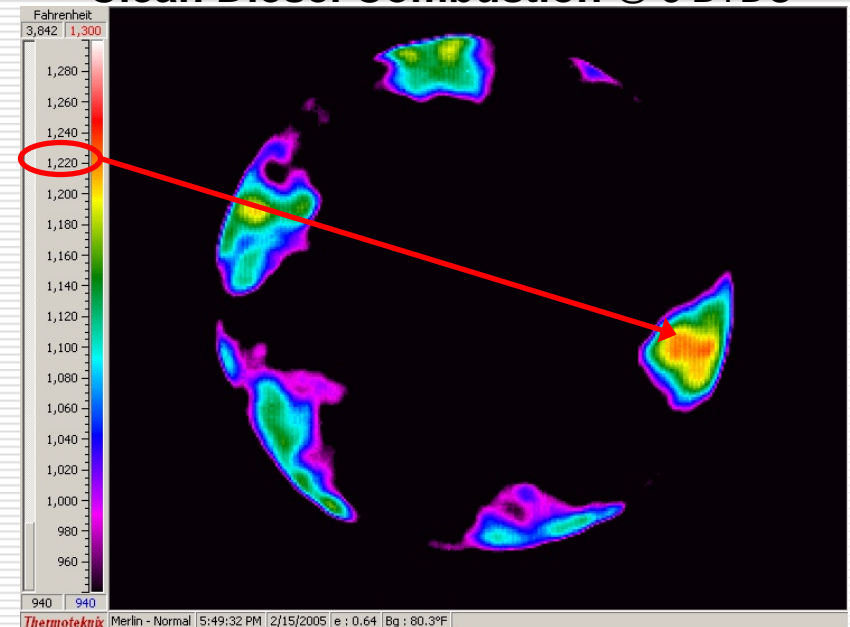
* Actual test speed was 1500 RPM

Normal Diesel Combustion @ 5-3 BTDC



Temp range: 940-3842 F, Exp time: 20 μ s,
Inj time: 17 BTDC, 20.8% Int O2

Clean Diesel Combustion @ 3 BTDC



Temp range: 940-3842 F, Exp time: 20 μ s,
Inj time: 25 BTDC, 108F Intake temp: 13.5% Int O2